Results in Engineering 11 (2021) 100261

Contents lists available at ScienceDirect

Results in Engineering

journal homepage: www.sciencedirect.com/journal/results-in-engineering

Sound pressure level of a Formula 3 car and the influence of detachable muffler-tip

Arun Arjunan *, Ahmad Baroutaji

Additive Manufacturing of Functional Materials Research Group, Centre for Engineering Innovation and Research, University of Wolverhampton, Telford Innovation Campus, TF2 9NT, UK

ARTICLE INFO

Keywords:
Formulae 3
Racing
Sound pressure level
Silencer
Finite element method

ABSTRACT

This study presents the initial findings associated with the noise emission tests that were carried out in preparation of the UWR Formula 3 car. Even though Formula 3 (F3) race cars are excluded from road vehicle noise emission regulations (EU No. 540/2014), their emission is closely regulated by Fédération Internationale de l'Automobile (FIA) technical regulations. According to FIA regulations, the noise generated by participating cars must not exceed 110 dB (A-weighted) under specific test conditions. The acoustic tests presented in this study were carried out at RAF (Royal Air Force) Cosford airfield in the UK closely simulating FIA recommended conditions. The tests were established to characterise the noise emission of the car during drive-by and stationary conditions. In addition to measuring the Sound Pressure Level (SPL) emitted, the study was extended to evaluating the performance of a detachable muffler tip that is permitted under the FIA regulations. The study found that the tested muffler-tip did not reduce the LAeq acoustic emission under any of the test cases considered. Nevertheless, introducing muffler-tip worsened the LAeq levels by 0.2 dB which is within the standard acoustic measurement uncertainty. Overall, the paper establishes the noise levels associated with F3 cars and the requirement for customised muffler-tips as opposed to aftermarket ones for meaningful noise reduction without adversely affecting performance.

1. Introduction

Literature on the levels of noise emitted by motor racing vehicles or events in the UK are scarce. According to an Australian study conducted by Tranter and Lowes [1], noise levels from Formula cars are similar to those produced by a jet plane taking off. The authors also suggest that noise pollution from motorsport penetrates buildings, and its impact worsens in circuits close to densely populated urban areas.

From available data, NASCAR (National Association of Stock Car Racing) have shown noise levels significantly higher than the acceptable occupational daily dose of 85 dB as summarised in Table 1 [2]. Noise levels in a Formula 1 (F1) event can go up to 140 dB, enough to cause permanent hearing loss [3]. This sustained over an entire race event is well above the HSE (Health and Safety Executive) regulations as listed in Table 1. As such adverse health effects health effects noise pollution is a serious concern for those involved in motorsports. Racing fans are also exposed to such noise levels at race events that can cause permanent damage to hearing [4–6].

The impact of noise emission associated with motorsport events can vary depending upon the location. For example, noise emission can be high if an event is in a high-density urban area. A new test method for the measurement of noise emission was introduced as part of the 2011 revised EU regulation for motor vehicles [7]. The most important aspect of the report was the introduction of more stringent limit values for noise emission. These limit increases were based on the VENOLIVA [8] study, which looked at both the social and health impacts of traffic noise which are well documented [9–13]. However, literature on noise associated with motor racing are still scare and an area that need significant data collection. As such, there is a need to study the noise levels associated with motor racing to raise wider awareness and development suitable recommendations. The recommendations can be range from the use of personalised ear protection to appropriate noise warning and acoustic education [14–16]. This is increasingly important as according to World Health Organisation (WHO) report at least 360 million people worldwide have suffered from disabling hearing loss [17–19].

The University of Wolverhampton (UoW) runs a Formula 3 (F3)

* Corresponding author. School of Engineering, Faculty of Science and Engineering University of Wolverhampton, Telford Innovation Campus, Telford, TF2 9NT, UK.

E-mail address: a.arjunan@wlv.ac.uk (A. Arjunan).

https://doi.org/10.1016/j.rineng.2021.100261
Received 29 June 2021; Received in revised form 27 July 2021; Accepted 28 July 2021
Available online 30 July 2021
2590-1230/

Table 1
Noise exposure limits and effects highlighting current levels associated with motor racing.

Sound level (dB)	Maximum allowable exposure	Adverse effect
10	24 Hours	None
60	12 Hours	Annoyance
85	8 Hours	Risk of hearing loss
88	4 Hours	Risk of hearing loss
91	2 Hours	Risk of hearing loss
94	1 Hour	Risk of hearing loss
97	30 Minutes	Risk of hearing loss
100 (NASCAR, F1, F3)	15 Minutes	Hearing loss
106 (NASCAR, F1, F3)	7.5 Minutes	Hearing loss
109 (NASCAR, F1, F3)	<2 Minutes	Hearing loss
112 (NASCAR, F1, F3)	<1 Minute	Hearing loss
130 (NASCAR, F1)	0	Painful/dangerous
140	0	Painful/dangerous

racing team under the name UWR (University of Wolverhampton Racing). The car as shown in Fig. 1 is set up by a team of students, technicians, and academics at the school of engineering and driven by professional racing driver Shane Kelly. Given the lack of data around noise emission associated with F3 cars, it was necessary to study the sound levels associated to derive guidelines for testing and preparation.

This objective was to understand the sound pressure levels of the car in semi-free field conditions and the influence of removable muffler tips. The influence of muffler-tip is analysed both experimentally and using the Finite Element Method (FEM). FEM is a widely used technique for a range of engineering problem [20–22], including the design of race car components [23]. Acoustic modelling [24–26] using FEM has been widely used to study the performance of various structures. Notable works include the use of FEM to evaluate complex muffler designs by Jones and Kessissoglou [27] who showed good agreement between experimental and numerical techniques. Research by Mimani and Munjal [28] successfully using FEM to evaluate the behaviour of an elliptical muffler having an end-inlet.

Other works include the use of numerical modelling to evaluate the destructive interference phenomenon such as the ones in the Herschel-Quincke (H-Q) tube phenomenon [29–32]. The effects of expansion chamber parameters like length, duct extension and diametric ratio were studied by Kang and Ji [33]. A 3D FEA model for concentric and extended tube resonators was developed by Munjal [34] to analyse perforated bridge designs for improved acoustic performance. Despite these studies, the use of numerical or experimental methods to analyse the effect of detachable muffler-tip are yet to be studied.

Overall, the study establishes the sound pressure level of an F3 car under semi-free field conditions (where reflections from the only ground are considered) closely simulating FIA recommended guidelines for the first time. Acoustic measurements were carried out to evaluate the noise emission of the car during drive-by and stationary conditions. Furthermore, the influence of detachable muffler-tip on the noise emission level of the car is also characterised both experimentally and using FEM.

2. Methodology

2.1. Finite element analysis

This study employs a 3D FEM in the frequency domain using the time-harmonic pressure acoustic application mode. As such, a modified version of the Helmholtz equation for the acoustic pressure p was considered as shown in Eq. (1):

$$\nabla\cdot\left(-\frac{\nabla p}{\rho}\right)-\frac{\omega^2 P}{{c_s}^2\rho}=0 \tag{1}$$

where ρ is the density, c_s is the sonic velocity and ω is the angular frequency. The equivalent fluid attenuation for the perforated section of the silencer was modelled using Delany-Bazley and Miki models for respective frequency where the complex impedance (Z_c) is defined Eq. (2) and the complex propagation constant is defined by Eq. (3):

$$Z_c=R+jX \tag{2}$$

$$\gamma=\alpha+jB \tag{3}$$

where R is the resistance, X is the reactance, α is the attenuation constant and β is the phase constant modelled by Eqs. (4)–(7) respectively:

$$R=\rho_0 c_0\left\{1+a\left(\frac{f}{\sigma}\right)^b\right\} \tag{4}$$

$$X=-\rho_0 c_0\left\{c\left(\frac{f}{\sigma}\right)^d\right\} \tag{5}$$

$$\alpha=\frac{\omega}{c_0}q\left(\frac{f}{\sigma}\right)^r \tag{6}$$

$$\beta=\frac{\omega}{c_0}\left\{1+s\left(\frac{f}{\sigma}\right)^t\right\} \tag{7}$$

where f is the frequency and σ is the fluid resistivity. The respective

Table 2
Coefficients used to obtain approximate functions for Delany-Bazley and Miki models for FEM.

Coefficient	Delany-Bazley	Miki
a	0.0497	0.0699
b	−0.754	−0.632
c	0.0758	0.107
d	−0.732	−0.632
q	0.169	0.160
r	−0.618	−0.618
s	0.0858	0.109
t	−0.700	−0.618

Fig. 1. UWR Formula 3 car.

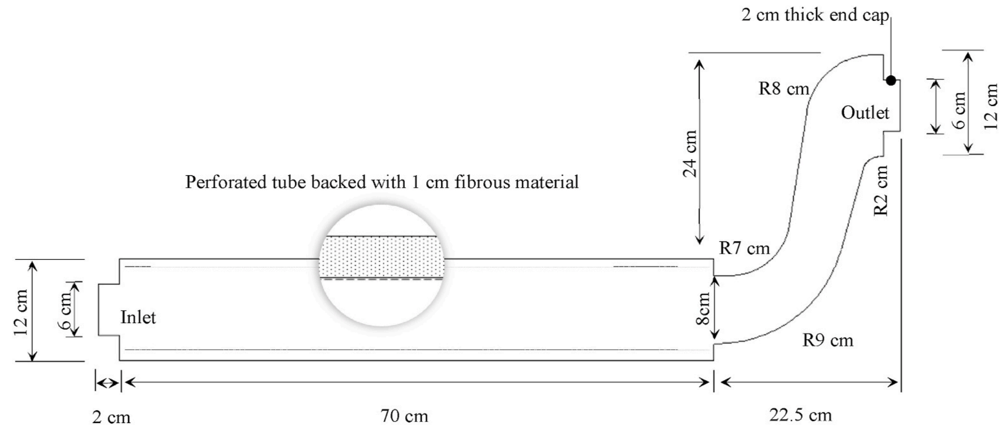

Fig. 2. Dimensions for the silencer considered for numerical modelling.

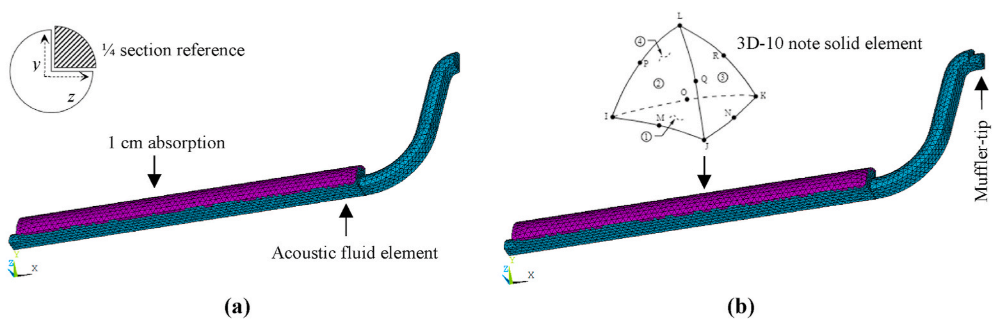

Fig. 3. Finite element meshed quarter model showing (a) without muffler-tip and (b) with muffler-tip.

coefficients for powers using in the respective equations to yield approximation functions are summarised in Table 2. The proposed working range for the Delany-Bazley model is $0.01 < f/\sigma < 1$ whereas the Miki model can be extended to $0.01 < f/\sigma$.

The dimensions of the muffler used for FE modelling is as shown in Fig. 2; two 3D quarter section (90° rotated) models were created one without muffler-tip (Fig. 3a) and one with the tip (Fig. 3b). For both the models the perforated absorption section of the silencer was modelled with acoustic fluid elements with a resistivity value of 4896 N s/m^4. This material was lined along the periphery of the dissipative section of the silencer at 1 cm thickness as shown in Fig. 3. All other areas were modelled with acoustic fluid elements representing air with a density of 1.21 kg/m^3 and sonic velocity of 343 m/s.

Acoustic harmonic analysis was carried out using the ANSYS Parametric Design Language (APDL). The 3D 10-node acoustic tetrahedral solid element (Fluid221) shown in Fig. 3b featuring the acoustic wave equation and pressure degree of freedom (DOF) was used to model the acoustic system under consideration. FLUID221 is a higher order solid element that exhibits quadratic pressure behaviour suitable for conceiving both the pressure part of the fluid medium and the interface in a fluid-structure interaction problems [35,36]. A quarter section model featuring Fluid221 elements with only pressure DOF was highly beneficial in terms of computational time, as the symmetric element matrices require less memory and can be executed efficiently.

The parameter of interest from the FEA analysis was the difference in SPL with and without the muffler-tip. Consequently, the sound source was modelled as an inward normal velocity of excitation (v_n) at the inlet nodes of the silencer. This was modelled as a function of unit pressure p, density ρ and sonic velocity c using Eq. (8):

$$v_n = \frac{-p}{\rho c} \tag{8}$$

Using the resultant amplitude from Eq. (8), the finite element solution for the pressure on the normal velocity excitation surface are obtained. The impedance boundary condition was also applied at the inlet port IMPD boundary flags. At the exit nodes (silencer outlet) infinity boundary conditions were specified to model an open domain. A mesh sensitivity analysis was carried out and found that the best results were obtained when the maximum element length (e_l) satisfied ten elements per wavelength as shown in Eq. (9):

$$e_l = \frac{c}{10f} \tag{9}$$

The FE model was solved for a case with and without end caps using an E5-2620 CPU at 2.1 GHz (12 CPUs) with 65,536 MB RAM coupled with NVIDIA MAXIMUS setting coupling a Quadro K6000 and Tesla K20. The FEA model used in this work averages 21,712 nodes and 13,255 elements and takes approximately 21 min to complete.

2.2. Experimental test

A total of four experimental test cases were considered for the initial assessment: two drive-by and two stationary test conditions. The test site was RAF Cosford and consisted of a level dense asphalt with no porosity. The surface was free from snow, grass, loose soil, or other sound-absorbing material. The tests were conducted on an open surface with the axial flow of the exhaust facing in a direction free from large reflecting surfaces. The average temperatures close to the microphone were between 7 and 10°C; the hygrometer reading was between a relative value of 81 %. Background noise was monitored between noise emission measurements to make sure that ambient and wind-induced noise was at least 10 dB below the A-weighted SPL.

The microphone positioning for the test cases was as shown in Fig. 4. During drive-by, noise emission levels were measured for a speed of 40 (±5) mph and 60 (±5) mph. A class 1 broad-band Sound Level (SL) meter meeting the requirements in accordance with IEC 61672–1 [37]

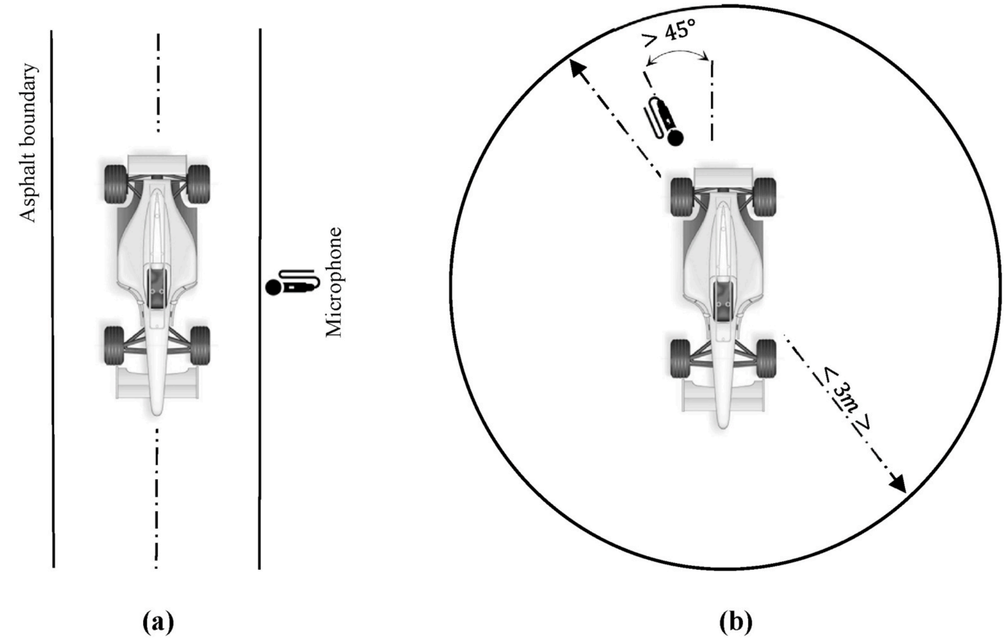

Fig. 4. Acoustic test setup for case (a) drive-by and (b) stationary.

Fig. 5. Silencer of the UWR F3 car, (a) full silencer (b) with end caps and (c) without end caps.

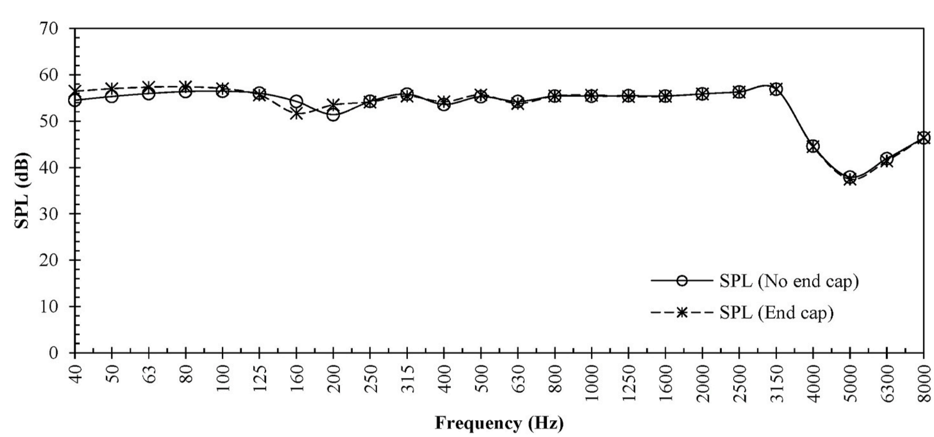

Fig. 6. SPL levels obtained from finite element simulation.

was used for the measurements. The microphones were mounted on a tripod to avoid data contamination from movement during measurement runs. In addition, a full windshield was used to limit the influence of wind loading and exhaust flow on the measured data. The microphones used were calibrated using IEC 60942:2003 [38] class 1 complaint acoustic calibrator.

For stationary noise emission, the vehicle was placed in neutral, and the engine rpm was gradually increased to 75 % of the rated engine speed as measured from the on-board tachometer. The noise emission levels were then measured for the car using the silencer (Fig. 5a) with and without the end caps as shown in Fig. 5b and c respective. The microphone was placed at no more than 0.5 m from the exhaust terminal. For all test cases, the microphone was positioned to coincide with the same lateral plane as that of the exhaust in parallel with the ground. The measurements were carried out for both the A-weighted and 1/3rd octave band range Sound Pressure Level (SPL).

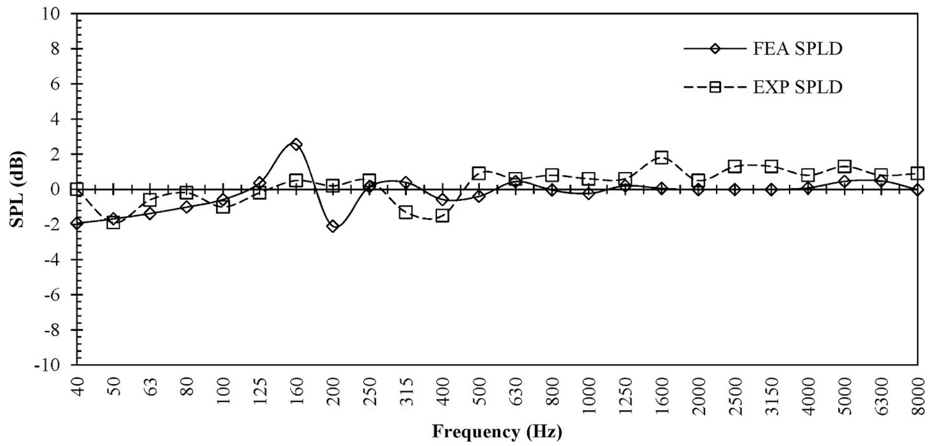

Fig. 7. SPLD between experimental and FEA.

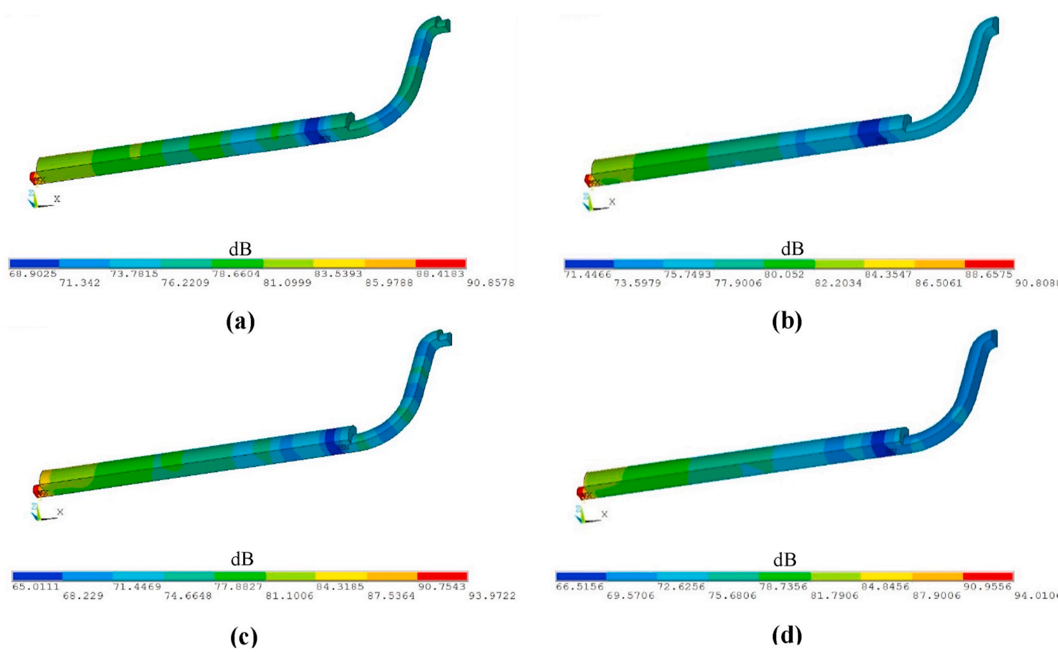

Fig. 8. Finite element SPL (dB) distribution with the silencer for (a) with end cap at 1000 Hz, (b) without end cap 1000 Hz, (c) with end cap at 1600 Hz and (d) without end cap 1600 Hz.

3. Results and discussion

3.1. Finite element analysis

The purpose of the FE study was to analyse the influence of muffler-tips on SPL, it was deemed useful to develop an acoustic model incorporating a simplified attenuation model. Fig. 6 presents the SPL obtained from the FE simulation for a case with and without muffler-tips. The simulation was conducted for a frequency range of 40 Hz–8000 Hz at a one-third octave band. The frequency range was limited because of the simplified attenuation coefficient used to model the boundary attenuation.

Comparing the SPL values, a similar trend can be observed with respect to experimental results. The key variable of interest here is the difference between SPL levels with and without end caps and not the numerical accuracy of the SPL values in comparison with the experimental test. For the current study, numerical values for SPL cannot be expected to be in the same range as the experimental test as the amplitude of noise source was modelled using an arbitrary value which is standard practice.

Fig. 7 shows the sound pressure level difference (SPLD) for experimental and FEA with and without muffler-tips. Comparing the results, the highest difference of 2.3 dB at 200 Hz, followed by 2 dB at 160 Hz was observed. On all other frequencies, the differences were below 2 dB, which can be considered a good agreement with experimental test data. The peak and valley at 160 dB and 200 Hz can be due to the influence of the Eigenmodes, consequently, these can be considered critical frequency for this geometry under FEA analysis.

In addition to the SPL, the numerical model allows visualising the spatial acoustic distribution in the muffler. This allows characterising the behaviour while considering the geometry of the muffler tip which can aid personalisation for acoustic effectiveness. The SPL distribution at 1000 Hz and 1600 Hz with and without the muffler tips are presented in Fig. 8(a–c). A difference in spatial SPL can be observed in both the cases presented after the introduction of the muffler tip. This can aid in optimising various aspects of the geometry of the silencer for targeted acoustic outcomes. Based on the results obtained, the 3D simplified FE modelling procedure presented can be used to predict the acoustic

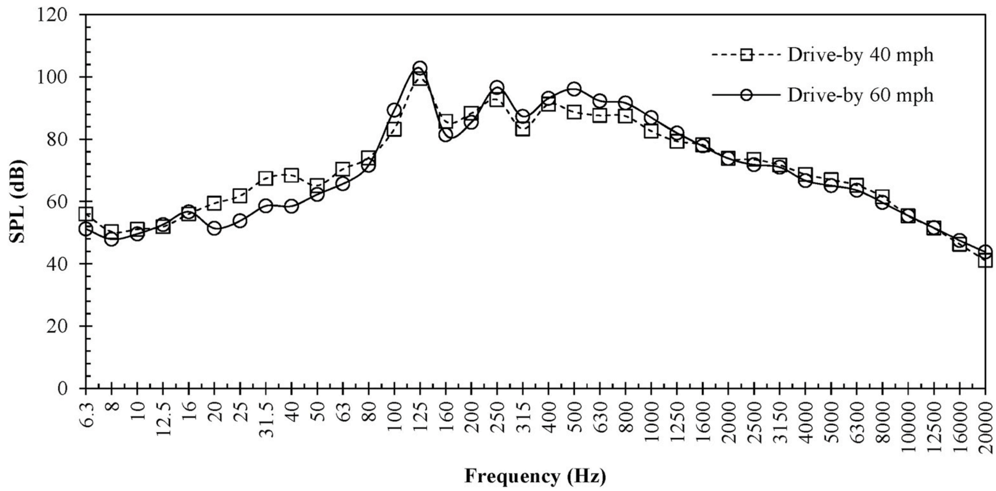

Fig. 9. Unweighted SPL measured at 1/3rd Octave band during drive-by.

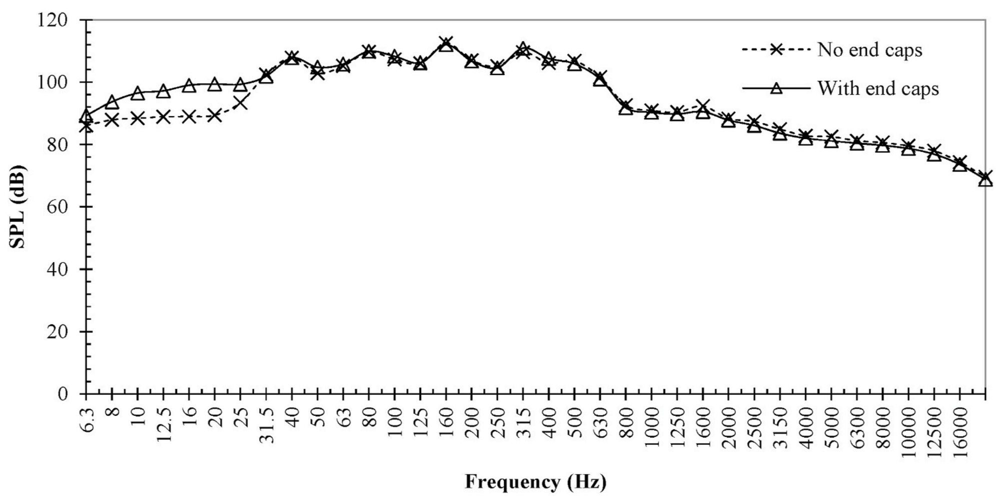

Fig. 10. Sound pressure levels measured when the car is stationary.

performance of a dissipative silencer. The FEA model presented is effective as it is an approximation model and can be executed efficiently. The SPL performance of race car silencers can help designers to test the performance of design alterations without the need for prototyping.

3.2. Sound pressure levels

The unweighted one-third-octave band range measurements from drive-by conditions at 40 mph and 60 mph are shown in Fig. 9. A slightly lower SPL was be observed for 60 mph compared to 40 mph at low frequencies (>100 Hz). Peak SPL values of 102.8 dB and 99.4 dB was observed at 125 Hz for 40 mph and 60 mph, respectively.

Based on the one-third spectrum data, the A-weighted single number rating LAeq was calculated to categorise the noise emission levels at drive-by. LAeq, is the equivalent single number which refers to the single number sound level that results in the same total sound energy being produced over a given period [39–41]. LAeq is a fundamental measurement parameter designed to represent a varying sound source over a given time as a single number. As such the LAeq is a representation of the energy contained within the sound at the point of the receiver. This is useful in terms of the potential for sound to damage or disturb and is extensively used in environmental noise standards and other regulations [42–44].

For the F3 car, the LAeq values of 94.3 dB and 98.4 dB was calculated for 40 mph and 60 mph, respectively. These values are consistent with noise levels associated with professional racing and within the regulated emission of 110 dB. Nevertheless, it should be noted that these are noise exposure levels measured under semi-free field conditions and can be expected to increase in the presentence of reflecting surfaces. Consequently, adequate precautions are necessary by all personnel at the race event to reduce the impact of noise exposure. In any case, exposure to noise levels above 110 dB above 2 min is not recommended and ear protection is recommended.

Fig. 10 shows the SPL levels measured at stationary with and without the muffler end-tips. For the unweighted SPL, peak values of 112 dB and 112.5 dB were observed at 160 Hz with and without endcaps, respectively. Comparing the performance, the endcap is contributing to a slight increase in unweighted SPL at low frequencies. Furthermore, the performance stayed the same with and without end caps at medium frequencies and only negligible improvements were observed after installing the end cap at high frequencies. As such the muffler-tip in its current form (geometry, material, stiffness, and mass) is not contributing to the reduction of noise emission under stationary conditions.

The LAeq values at stationary with and without end caps were found to be 109.8 dB and 110 dB respectively at semi-free field conditions. The results were found to match the F3 regulated value of 110 dB. However, the end cap slightly worsens the noise emission levels by increasing the LAeq values from 109.8 to 110.0 dB. Consequently, it is worth recommending that high-performance ear protection devices are necessary while testing the car. There is also a need for affordable high efficiency personalised ear protection where acoustic metamaterial [45, 46] can be exploited for frequency dependent sound reduction. The noise emission levels of 109.8–110 dB although consistent with motor racing are above the safe limits of exposure under current HSE noise regulations.

4. Conclusion

There have been no studies conducted in the UK in relation to the noise exposure of an F3 car. As such this research provides evidence about the noise levels that can be expected from a typical F3 car under stationery and drive-by conditions. Based on the semi-free field tests, noise emissions at 40 mph and 60 mph were found to be lower than stationary conditions. Even though the highest SPL emission level matched regulated 110 dB set by the FIA, this is above the safe level of noise exposure as stated by UK HSE. Analysing the influence of detachable muffler-tips permitted under F3 regulations, no significant improvement in noise reduction was observed. Introducing the muffler tips was found to slightly worsen the spectrum level measurements at low frequencies. Overall, effective hearing protection devices are recommended to all personnel that work with the race teams and attend the race event. The study also establishes a 3D numerical model with a simplified attenuation model using the finite element methodology. A good agreement was observed between the FEA and Experimental SPLD values for almost all frequencies other than for two critical frequencies. As such the numerical model developed in this study can be used to characterise the performance of the muffler tips for motor racing.

Credit author statement

Arun Arjunan: Conceptualisation, Supervision, Methodology, Software, Investigation, Validation, Formal analysis, Writing original draft, Writing- Reviewing and Editing. Ahmad Baroutaji: Conceptualisation, Methodology, Software, Investigation, Validation, Formal analysis, Writing original draft, Writing- Reviewing and Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research was conducted with support from the University of Wolverhampton and the UWR race team.

References

[1] P.J. Tranter, M.D. Lowes, The place of motorsport in public health: an Australian perspective, Health Place 11 (2005) 379–391, https://doi.org/10.1016/j.healthplace.2004.07.004.
[2] C.A. Kardous, T.C. Morata, Occupational and recreational noise exposures at stock car racing circuits: an exploratory survey of three professional race tracks, Noise Control Eng, J 58 (2010) 54–61, https://doi.org/10.3397/1.3270506.
[3] C.N. Dolder, J.I. Suits, P.S. Wilson, Noise exposure in the general audience of a Formula 1 race, J. Acoust. Soc. Am. 134 (2013) 4221, https://doi.org/10.1121/1.4831503.
[4] A. Rose, C.S. Ebert, J. Prazma, H. Pillsbury, Noise exposure levels in stock car auto racing, ENT J 87 (2008) 689–692.
[5] J. Lindemann, T. Brusis, Is there a risk of noise-induced hearing loss in automobile drivers and in automobile sport racing? Laryngol. Rhinol. Otol. 64 (1985) 476–480.
[6] S. Hadi Hassan Al-Taai, Noise and its impact on environmental pollution, Mater. Today Proc. (2021) https://doi.org/https://doi.org/10.1016/j.matpr.2021.05.013.
[7] F. de, Roo Michael Dittrich Casper Bosschaart Bernard Berry, Management Summary Title : Reduction of Vehicle Noise Emission-Technological Potential and Impacts, 2012.
[8] F. de Roo, M.G. Dittrich, P.J.G. van Beek, C. Bosschaart, D.G. Derksen, M. de Kievit, VENOLIVA - Vehicle Noise Limit Values - Comparison of Two Noise Emission Test Methods, Final Report, 2011 (accessed June 29, 2021), https://repository.tno.nl/islandora/object/uuid%3A1e8015fb-8df9-4b47-9f5b-2e87f6542462.
[9] I.A. Rossi, D. Vienneau, M.S. Ragettli, B. Flückiger, M. Röösli, Estimating the health benefits associated with a speed limit reduction to thirty kilometres per hour: a health impact assessment of noise and road traffic crashes for the Swiss city of Lausanne, Environ. Int. 145 (2020) 106126, https://doi.org/https://doi.org/10.1016/j.envint.2020.106126.
[10] A. Tobías, A. Recio, J. Díaz, C. Linares, Health impact assessment of traffic noise in Madrid (Spain), Environ. Res. 137 (2015) 136–140, https://doi.org/https://doi.org/10.1016/j.envres.2014.12.011.
[11] A.I. Pawelloi, N. Nasir, S. Hakzah, The effect of traffic noise on public health, Enfermería Clínica. 30 (2020) 249–253, https://doi.org/https://doi.org/10.1016/j.enfcli.2020.06.057.
[12] R. Meyer, E. Benetto, F. Mauny, C. Lavandier, Characterization of damages from road traffic noise in life cycle impact assessment: a method based on emission and propagation models, J. Clean. Prod. 231 (2019) 121–131, https://doi.org/https://doi.org/10.1016/j.jclepro.2019.05.185.
[13] K. Shaaban, A. Abouzaid, Assessment of traffic noise near schools in a developing country, Transp. Res. Procedia. 55 (2021) 1202–1207, https://doi.org/https://doi.org/10.1016/j.trpro.2021.07.100.
[14] C.D. Katsis, Y. Goletsis, G. Rigas, D.I. Fotiadis, A wearable system for the affective monitoring of car racing drivers during simulated conditions, Transport. Res. C Emerg. Technol. 19 (2011) 541–551, https://doi.org/https://doi.org/10.1016/j.trc.2010.09.004.
[15] A. Kusy, J. Châtillon, Real-world attenuation of custom-moulded earplugs: results from industrial in situ F-MIRE measurements, Appl. Acoust. 73 (2012) 639–647, https://doi.org/https://doi.org/10.1016/j.apacoust.2012.02.001.
[16] P.N. Sankov, V.V. Hilov, B.D. Gvadzhaia, V.N. Makarova, Acoustic safety of the living environment, IOP Conf. Ser. Mater. Sci. Eng. 1079 (2021) 42067, https://doi.org/10.1088/1757-899x/1079/4/042067.
[17] WHO, World Report on Hearing, Geneva, 2021. https://doi.org/978-92-4-002048-1.
[18] M.M. Metidieri, H.F.S. Rodrigues, F.J.M.B. de O. Filho, D.P. Ferraz, A.F. de A. Neto, S. Torres, Noise-Induced Hearing Loss (NIHL): literature review with a focus on occupational medicine, Int. Arch. Otorhinolaryngol. 17 (2013) 208–212, https://doi.org/10.7162/S1809-97772013000200015.
[19] Z. Jiang, B. Fa, X. Zhang, J. Wang, Y. Feng, H. Shi, Y. Zhang, D. Sun, H. Wang, S. Yin, Identifying genetic risk variants associated with noise-induced hearing loss based on a novel strategy for evaluating individual susceptibility, Hear. Res. 407 (2021) 108281, https://doi.org/https://doi.org/10.1016/j.heares.2021.108281.
[20] A. Godat, O. Chaallal, Y. Obaidat, Non-linear finite-element investigation of the parameters affecting externally-bonded FRP flexural-strengthened RC beams, Results Eng 8 (2020) 100168, https://doi.org/https://doi.org/10.1016/j.rineng.2020.100168.
[21] D.V.K. Prasad, G.S.K. Chaitanya, R.S. Raju, Double diffusive effects on mixed convection Casson fluid flow past a wavy inclined plate in presence of Darcian porous medium, Results Eng 3 (2019) 100019, https://doi.org/https://doi.org/10.1016/j.rineng.2019.100019.
[22] Z. El-Shaarawy, M. Talaat, A. El-Zein, Field reduction simulation based on covered conductors design in medium voltage lines, Results Eng 10 (2021) 100217, https://doi.org/https://doi.org/10.1016/j.rineng.2021.100217.
[23] G. Wheatley, M. Zaeimi, On the design of a wheel assembly for a race car, Results Eng 11 (2021) 100244, https://doi.org/https://doi.org/10.1016/j.rineng.2021.100244.
[24] A. Arjunan, C.J. Wang, K. Yahiaoui, D.J. Mynors, T. Morgan, V.B. Nguyen, M. English, Sound frequency dependent mesh modelling to simulate the acoustic insulation of stud based double-leaf walls. Proc. ISMA 2014 - Int. Conf. Noise Vib. Eng. USD 2014 - Int. Conf. Uncertain, Struct. Dyn., 2014.
[25] A. Arjunan, C. Wang, M. English, M. Stanford, P. Lister, A computationally-efficient numerical model to characterize the noise behavior of metal-framed walls, Metals 5 (2015) 1414–1431, https://doi.org/10.3390/met5031414.
[26] A. Arjunan, A. Baroutaji, A.S. Praveen, A.G. Olabi, C.J. Wang, Acoustic performance of metallic foams. Ref. Modul. Mater. Sci. Mater. Eng., Elsevier, 2019, https://doi.org/10.1016/B978-0-12-803581-8.11561-9.
[27] P. Jones, N. Kessissoglou, An Evaluation of Current Commercial Acoustic FEA Software for Modelling Small Complex Muffler Geometries: Prediction vs Experiment, 2009.
[28] A. Mimani, M.L. Munjal, 3-D acoustic analysis of elliptical chamber mufflers having an end-inlet and a side-outlet: an impedance matrix approach, Wave Motion 49 (2012) 271–295, https://doi.org/https://doi.org/10.1016/j.wavemoti.2011.11.001.
[29] V. Sagar, M.L. Munjal, Analysis and design guidelines for fork muffler with H-connection, Appl. Acoust. 125 (2017) 49–58, https://doi.org/https://doi.org/10.1016/j.apacoust.2017.04.007.
[30] A. Arjunan, Targeted sound attenuation capacity of 3D printed noise cancelling waveguides, Appl. Acoust. 151 (2019) 30–44, https://doi.org/10.1016/j.apacoust.2019.03.008.
[31] A. Arjunan, Acoustic absorption of passive destructive interference cavities, Mater. Today Commun. 19 (2019) 68–75, https://doi.org/10.1016/j.mtcomm.2018.12.012.
[32] A. Arjunan, A. Baroutaji, A. Latif, Acoustic behaviour of 3D printed titanium perforated panels, Results Eng 11 (2021) 100252, https://doi.org/https://doi.org/10.1016/j.rineng.2021.100252.

[33] Z. Kang, Z. Ji, Acoustic length correction of duct extension into a cylindrical chamber, J. Sound Vib. 310 (2008) 782–791, https://doi.org/https://doi.org/10.1016/j.jsv.2007.11.005.

[34] M. Munjal, Theory and Design of Tuned Extended-Tube Chambers and Concentric Tube Resonators, 2009.

[35] A. Arjunan, C.J. Wang, K. Yahiaoui, D.J. Mynors, T. Morgan, V.B. Nguyen, M. English, Development of a 3D finite element acoustic model to predict the sound reduction index of stud based double-leaf walls, J. Sound Vib. 333 (2014) 6140–6155, https://doi.org/10.1016/j.jsv.2014.06.032.

[36] A. Arjunan, C.J. Wang, K. Yahiaoui, D.J. Mynors, T. Morgan, M. English, Finite element acoustic analysis of a steel stud based double-leaf wall, Build. Environ. 67 (2013) 202–210, https://doi.org/10.1016/j.buildenv.2013.05.021.

[37] BS EN 61672-1, Sound Level Meters, Specifications, London, 2013. https://shop.bsigroup.com/ProductDetail?pid=000000000030208586. (Accessed 29 June 2021), 2013 - Electroacoustics, accessed.

[38] BS EN 60942:2003 - Electroacoustics, Sound calibrators, London, 2003. https://shop.bsigroup.com/ProductDetail/?pid=000000000030090951. (Accessed 29 June 2021). accessed.

[39] M. Dearden, A.W. Jennison, Prediction of LAeq for motor racing noise, Appl. Acoust. 28 (1989) 277–283, https://doi.org/https://doi.org/10.1016/0003-682X(89)90085-6.

[40] E. Freitas, C. Mendonça, J.A. Santos, C. Murteira, J.P. Ferreira, Traffic noise abatement: how different pavements, vehicle speeds and traffic densities affect annoyance levels, Transport. Res. Transport Environ. 17 (2012) 321–326, https://doi.org/https://doi.org/10.1016/j.trd.2012.02.001.

[41] N. Garg, S. Maji, A critical review of principal traffic noise models: strategies and implications, Environ. Impact Assess. Rev. 46 (2014) 68–81, https://doi.org/https://doi.org/10.1016/j.eiar.2014.02.001.

[42] E. D'Hondt, M. Stevens, A. Jacobs, Participatory noise mapping works! an evaluation of participatory sensing as an alternative to standard techniques for environmental monitoring, Pervasive Mob. Comput. 9 (2013) 681–694, https://doi.org/https://doi.org/10.1016/j.pmcj.2012.09.002.

[43] L.P. Sánchez Fernández, Environmental noise indicators and acoustic indexes based on fuzzy modelling for urban spaces, Ecol. Indicat. 126 (2021) 107631, https://doi.org/https://doi.org/10.1016/j.ecolind.2021.107631.

[44] A. Zagubień, K. Wolniewicz, Impact of measuring microphone location on the result of environmental noise assessment, Appl. Acoust. 172 (2021) 107662, https://doi.org/https://doi.org/10.1016/j.apacoust.2020.107662.

[45] A. Arjunan, A. Baroutaji, J. Robinson, Advances in acoustic metamaterials. Ref. Modul. Mater. Sci. Mater. Eng., Elsevier, 2021 https://doi.org/https://doi.org/10.1016/B978-0-12-815732-9.00091-7.

[46] A. Arjunan, A. Baroutaji, J. Robinson, C. Wang, Characteristics of acoustic metamaterials. Ref. Modul. Mater. Sci. Mater. Eng., Elsevier, 2021 https://doi.org/https://doi.org/10.1016/B978-0-12-815732-9.00090-5.